NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

June 1946 as
Memorandum Report E6E16

INVESTIGATION OF ICE FORMATION IN THE INDUCTION SYSTEM OF AN AIRCRAFT ENGINE

II - FLIGHT TESTS

By Henry A. Essex, Carl Ellisman
and Edward D. Zlotowski

Aircraft Engine Research Laboratory
Cleveland, Ohio

NACA

WASHINGTON

NACA AIRCRAFT ENGINE RESEARCH LABORATORY

MEMORANDUM REPORT

for the

Air Materiel Command, Army Air Forces

INVESTIGATION OF ICE FORMATION IN THE INDUCTION SYSTEM OF AN AIRCRAFT ENGINE

II - FLIGHT TESTS

By Henry A. Essex, Carl Ellisman
and Edward D. Zlotowski

SUMMARY

Flight tests were conducted on a twin-engine fighter airplane at pressure altitudes up to 10,000 feet with simulated conditions of moderate, heavy, and excessive rain to determine the increase in enthalpy of the charge air due to the turbosupercharger, to determine the rate of enthalpy increase of the charge air resulting from a sudden increase of engine power, and to compare the conditions that caused induction-system icing in flight with those that resulted in icing of the same carburetor and supercharger inlet elbow in laboratory tests.

The alternate air system reduced the susceptibility to icing by excluding water and by increasing the heat input. The most effective ice protection was found to be obtainable by operating with closed intercooler flap, by timely use of the alternate air system, and by increasing power in order to provide more heat from the turbosupercharger. The effective turbosupercharger heat input was appreciably reduced because complete stoppage of the intercooler cooling-air flow was found to be impossible. The maximum heat rise available at the carburetor deck was not obtained until approximately 3 minutes after engine power was suddenly increased and appeared insufficient to de-ice the induction system quickly enough if serious icing occurred.

None of the flight tests resulted in serious carburetor icing and the induction system was found to be susceptible to serious icing only during low power operation at low altitudes

with high rates of water ingestion, which indicated that the laboratory-determined conditions for serious icing are conservative. The most serious carburetor air-flow reduction in these tests resulted from heavy impact icing, which blocked the carburetor air scoop and prevented operation of the alternate air valve.

INTRODUCTION

At the request of the Air Materiel Command, Army Air Forces, a general investigation of the formation and elimination of ice in the induction system of a twin-engine fighter airplane has been conducted at the NACA Cleveland laboratory. The experimental work was divided into four separate parts: laboratory tests of a carburetor and engine-stage supercharger assembly installed in a laboratory duct setup; dynamometer tests of a complete engine; ground tests of the complete induction system in the airplane; and actual flight tests with simulated-rain ingestion. The flight tests reported herein, which were conducted from March to May 1945, furnished data that were unobtainable in the laboratory and ground tests (references 1 and 2, respectively) because the effects of the turbosupercharger and the intercooler at altitude could be satisfactorily reproduced only in flight.

The laboratory tests of the carburetor and supercharger assembly (reference 1) determined the limiting-icing conditions in terms of charge-air enthalpy (termed "heat content" in reference 1) and total water content at the carburetor deck, as well as the effects of several other variables. Unpublished multicylinder-engine test results agreed favorably with the limiting-icing conditions previously determined in the laboratory tests and gave additional justification for the arbitrarily chosen criterions for serious icing. The approximate ranges of charge-air enthalpy and total water content at the carburetor deck that result in icing conditions were determined in the ground tests reported in reference 2.

The specific objectives of the flight tests were as follows: (a) to determine quantitatively the heat added to the charge air by the turbosupercharger and the resulting increase in charge-air enthalpy at the carburetor deck; (b) to determine the rate of increase in charge-air enthalpy at the carburetor deck following a sudden increase in engine power; (c) to compare the flight conditions of charge air at the carburetor deck and at the external air scoop with the limiting-icing conditions established at the carburetor deck in laboratory tests; and (d) to determine the effects of icing of the air-scoop elbow on the functioning of the induction system.

APPARATUS

The instrumented induction system of the test engine of the fighter airplane is shown in figure 1 and is fully described in reference 2. The additional instrumentation for the flight tests included a swivel-head static tube for determining altitude, a resistance-bulb thermometer calibrated for speed effects, and several shielded total-temperature thermocouples for measuring ambient-air temperature. The sections of ducting containing the observation ports used in the ground tests were replaced by standard duct sections.

During most flight tests, the charge-air inlet temperature, the static pressure, and the dew point were measured just inside the scoop (station 1, fig. 1). When the alternate air system was in use, however, the charge-air temperature and the static pressure were measured at the turbosupercharger inlet (station 2), but the charge-air dew point was measured at station 1 because the humidity at station 2 was not substantially different from that of the free air when no rain was simulated.

DESCRIPTION OF TESTS

The temperature of the fuel-air mixture, of the simulated rain, and of the fuel were continuously recorded throughout the flight tests.

The rates at which water was sprayed into the carburetor and intercooler air scoops, as explained in reference 2, were estimated for a true airspeed of 350 miles per hour and rain densities of 0.5, 1.0, and 2.0 grams of water per cubic meter of air, which represent moderate, heavy, and excessive rain, respectively (reference 3). Calculations showed that, at an airspeed of 350 miles per hour and with rain-droplet diameters larger than 400 microns, most of the intercepted rain would enter the intake regardless of the quantity of air entering the scoop. Most of the flight tests, however, were conducted at true airspeeds less than 350 miles per hour and, because no attempt was made to regulate the simulated-rain sprays in proportion to the airspeed, the actual simulated-rain densities were higher than the original estimates.

The method of conducting the flight tests was similar to that developed for the ground tests reported in reference 2. At the desired altitude, the engine conditions of manifold pressure and speed were set for both engines. When the air temperature had stabilized, the automatic recording units were started and at the same time the water flows to both the scoop and the intercooler duct were started at preset rates. During the tests, the pilot recorded the indicated dew-point temperatures, the free-air temperature, the carburetor-air temperature, and the positions of the throttle and the exhaust waste gate.

The flight tests were conducted in three series for which the test conditions and induction-system configurations are listed in tables I, II, and III. Tests 1 to 4 (table I) were made to study the effect of intercooler-flap setting and the effect of alternate-air intake on charge-air enthalpy in dry air at various power settings. The determination of the increase in rate of enthalpy resulting from sudden increases in engine power was made in dry air at altitudes of 5000 feet in tests 5 to 7 and 10,000 feet in tests 8 to 10 (table II). Tests 11 to 14 and 15 to 18 (table III) were made at altitudes of 5000 and 10,000 feet, respectively, to determine the net increase in charge-air enthalpy at the carburetor deck in dry air and in simulated rain of various intensities and to correlate the icing in flight with that observed in the laboratory tests of reference 1.

RESULTS AND DISCUSSION

Heat Supplied by the Turbosupercharger

Intercooler flap open. - Under all flight conditions encountered in these tests, the charge-air enthalpy was increased in passing through the turbosupercharger and the amount of increase was greater at high than at low manifold pressures. Because the exhaust waste-gate position for a given power condition was determined by the throttle setting, the manifold pressure at which the turbosupercharger began effective operation decreased with altitude and the amount of increase in charge-air enthalpy at any manifold pressure increased with pressure altitude.

At a pressure altitude of 5000 feet in clear air, the enthalpy increase across the turbosupercharger did not exceed 6 Btu per pound of air below a manifold pressure of 42 inches of mercury absolute but reached 11 Btu per pound at 50 inches of mercury absolute (fig. 2). At a pressure altitude of 10,000 feet, the enthalpy increase at manifold pressures below 32 inches of mercury absolute was apprximately the same as that for 5000 feet but reached 19 Btu per pound at a manifold pressure of 50 inches of mercury. Neither the trend nor the values of enthalpy increase were significantly changed by the ingestion of large amounts of simulated rain.

The data plotted in figure 3 are the results of a typical flight test to determine the effect of the intercooler on the charge-air enthalpy. In level flight at any altitude, an increase in engine power resulted in higher airspeed and the resulting increase in the mass flow of intercooler-cooling air largely offset the increase in turbosupercharger heat input. The net increase in charge-air enthalpy at the carburetor deck was only 2 Btu per pound at a pressure altitude of 5000 feet and 4 Btu per pound at 10,000 feet at a manifold pressure of 44 inches of mercury in clear air.

Intercooler flap closed. - In clear air at an altitude of approximately 3500 feet, when the alternate air intake was used, approximately two-thirds of the turbosupercharger heat input was removed because of the leakage of cooling air past the closed intercooler flap (fig. 4 (a)), but the net gain in charge-air enthalpy was greater than for the runs with ram air intake at the same altitude (fig. 4 (b)). The net gain in charge-air enthalpy was greater because, for a given manifold pressure, the pressure drop through the air filter in the alternate air intake requires a wider throttle opening than the ram air intake, which results in an earlier operation of the turbosupercharger and a corresponding increase in the heat supplied to the charge air. The net increase in charge-air enthalpy at a manifold pressure of 44 inches of mercury was only 5 Btu per pound with alternate air and 3 Btu per pound with ram air intake.

The possibility of induction-system icing is lessened when the alternate air intake is used, not only because the available turbosupercharger heat input is greater but also because free water is prevented from entering the induction system.

Rate of increase in charge-air enthalpy resulting from sudden increase of engine power. - In figures 5, 6, and 7, the change in charge-air temperature and enthalpy at the carburetor deck is presented for sudden increases in power from the reference setting of 60-percent rated power at altitudes of 5000 and 10,000 feet in clear air.

With ram air intake and intercooler flap open and closed at a pressure altitude of 5000 feet (figs. 5 (a) and 6 (a), respectively), the net change in enthalpy was less than 1 Btu per pound. When the ram air intake was switched to alternate air intake and the intercooler flap was closed, net enthalpy increases of 1 and 5 Btu per pound were obtained by increasing power to 75-percent and 100-percent normal rated power, respectively, with a maximum rate of enthalpy increase of 2 Btu per pound per minute for 100-percent normal rated power (fig. 7 (a)).

The net enthalpy increase at an altitude of 10,000 feet was negligible with ram air intake and intercooler flap open (fig. 5 (b)) but, during tests with the intercooler flap closed (fig. 6 (b)), a net increase in charge-air enthalpy of nearly 4 Btu per pound occurred 2 minutes after power was increased to approximately 90-percent normal rated power with a maximum increase in rate of enthalpy of 2.5 Btu per pound per minute. Figure 7 (b) shows that, when the ram air intake was changed to the alternate air intake as power was increased with the intercooler flap closed, the net enthalpy increase was 7 Btu per pound of charge air in 4 minutes when power was increased to approximately 90-percent normal rated power and 9 Btu in 3 minutes when power was increased to 100-percent normal rated power. The maximum increases in rate of enthalpy were 3.0 and 4.0 Btu per pound per minute for increases of engine power to 90-percent and 100-percent normal rated power, respectively.

The additional heat rise available from the turbosupercharger when power was increased from 60- to 100-percent normal rated power appears inadequate for effective de-icing of this induction system when compared with that used to de-ice the laboratory setup as reported in reference 4. In table I of reference 4, it is shown that de-icing time of the laboratory setup was 0.6 minute or less when the enthalpy of heated charge air was more than 27 Btu per pound greater than that of the icing charge air. Up to 9 minutes were required for de-icing with enthalpy increases of slightly less than 27 Btu. Reliance on increase of turbosupercharger heat input for emergency de-icing appears hazardous because of the length of time required to obtain the full heat rise and the availability of a maximum enthalpy increase of only 9 Btu per pound under the most favorable conditions at normal rated power.

Correlation of laboratory and flight-test results. - Limiting-icing-conditions curves of carburetor-air temperature and water content for a simulated altitude of 2000 feet as determined in the laboratory tests of reference 1 for low-cruise, high-cruise, and normal-rated-power conditions are reproduced in figures 8, 9, and 10, respectively. The criterion for serious icing in the induction system had been selected as a 2-percent reduction of initial air-flow rate in 15 minutes but most instances of serious icing resulted in 10 minutes (reference 1); therefore, 10-minute flight test runs were deemed satisfactory. The charge-air temperature and humidity conditions at the carburetor top deck observed in the flight tests are presented on these limiting-conditions curves for corresponding engine powers.

At low cruise power, or 60-percent rated power, four runs resulted in carburetor-deck conditions that fell into the serious-icing region, as determined from the laboratory data, but did not result in serious icing during the 10-minute duration of the flight runs. The one test flight at high cruise power (fig. 9), for which the carburetor-deck conditions occurred in the serious-icing region, did not result in serious icing. At normal rated power (fig. 10), none of the flight tests resulted in conditions of carburetor air in the serious-icing region.

The actual reductions in air-flow rate caused by icing during these tests were found to be greater at an altitude of 5000 feet than at 10,000 feet for a given power condition, and they were found to be greater during low power operation than high power operation for a given altitude. These results corroborate those of reference 1, which show that the severity of carburetor icing decreases as the throttle angle increases. This throttle-angle effect and the fact that AN-F-28, Amendment-2, fuel was used in the flight tests, instead of the more volatile AN-F-22 fuel used in the laborator tests of reference 1, probably account for the fact that the laboratory-determined limiting-icing conditions appear conservative. It is evident from a comparison of the flight and laboratory limiting-icing data that the smaller throttle angles and the more volatile fuel used in the laboratory tests produced carburetor icing more severe than encountered in flight at pressure altitudes above 2000 feet. Therefore, only during flight operation at low altitude and low power with high water-ingestion rates are the carburetor conditions likely to produce serious icing.

Impact icing. - The ambient-air temperature during three test flights was below 32° F and, consequently, when water was injected into the carburetor and intercooler air scoops, impact icing occurred in the carburetor-air scoop elbow and on the intercooler core. Ice accumulated at the inlet elbow of the carburetor-air scoop in sufficient quantity to render the alternate air selector valve inoperable and to cause serious air-flow losses. Time records of air-flow rate and manifold pressure for runs made with an initial manifold pressure of 35 inches of mercury absolute are presented in figure 11.

An accumulation of impact ice at the face of the intercooler prevented effective intercooling and permitted the charge-air enthalpy at the carburetor deck to rise above the limits of serious carburetor icing. Inasmuch as it has been shown that the laboratory-determined limits of serious icing are conservative when applied to flight conditions at an altitude of 10,000 feet, carburetor icing caused by fuel evaporation could not have been present.

One impact icing run (fig. 11 (b)) that did not cause a serious air-flow drop was made with the alternate air valve frozen in the alternate position. The valve could not be freed by manipulation of the selector valve control and the ice lasted until after the airplane returned to the ground.

SUMMARY OF RESULTS

The following results were obtained from flight tests of the twin-engine fighter airplane made at pressure altitudes of 3500, 5000, and 10,000 feet and are applicable to operation at these altitudes:

1. No serious carburetor icing was encountered during these tests and results indicated that the airplane induction system is susceptible to serious carburetor icing only during low power operation at low altitudes with high rates of water ingestion.

2. The flight test data indicate that the laboratory-determined conditions for serious icing are conservative.

3. The susceptibility to icing is reduced by using the alternate air intake, not only because water is excluded but also because wider throttle openings are required and increased turbosupercharger heat input results from the increased pressure losses.

4. The most serious air-flow reduction was not due to carburetor icing but occurred when the alternate air valve was frozen shut by impact ice in the air intake and could not be freed by manipulation of the controls.

5. During icing at subfreezing ambient-air temperature, the face of the intercooler became blocked with ice and, consequently, more of the turbosupercharger heat input was retained by the charge air to prevent icing at or below the carburetor.

6. The maximum available enthalpy increase of 9 Btu per pound of charge air that occurred approximately 3 minutes after a sudden increase to rated engine power with alternate air intake and intercooler flap closed is, according to laboratory-test results, insufficient to de-ice this induction system in an emergency if serious carburetor icing were to occur.

7. The induction system probably will ice only at low engine power; at low altitude and with high rates of water ingestion: serious icing can be prevented by proper operation of the airplane.

8. Protection from icing may be obtained by operating the airplane with the intercooler flap closed, by using the alternate air system before the valve becomes frozen with impact ice, and by increasing engine power in order to open the throttles wider and to increase the turbosupercharger heat input.

9. More of the turbosupercharger heat input could be retained by the charge air for emergency de-icing and ice prevention if the intercooler flap were tight enough to prevent the flow of all cooling air through the intercooler.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCES

1. Essex, Henry A., Keith, Wayne C., and Mulholland, Donald R.: Laboratory Investigation of Icing in the Carburetor and Supercharger Inlet Elbow of an Aircraft Engine. II - Determination of the Limiting-Icing Conditions. NACA MR No. E5L18a, 1945.

2. Essex, Henry A., Zlotowski, Edward D., and Ellisman, Carl: Investiation of Ice Formation in the Induction System of an Airplane Engine. I - Ground Tests. NACA MR No. E6B28, 1946.

3. Humphreys, William J.: Physics of the Air. McGraw-Hill Book Company, Inc., 3d ed., 1940, p. 280.

4. Lyons, Richard E., and Coles, Willard D.: Laboratory Investigation of Icing in the Carburetor and Supercharger Inlet Elbow of an Aircraft Engine. III - Heated Air as a Means of De-Icing the Carburetor and Supercharger Inlet Elbow. NACA MR No. E5L19, 1945.

TABLE I - INVESTIGATION OF EFFECT OF INDUCTION-SYSTEM

CONFIGURATION ON CHARGE-AIR ENTHALPY IN DRY AIR

Test	Pressure altitude	Manifold pressure (in. Hg absolute)	Engine speed (rpm)	Intercooler-flap setting	Charge-air intake
1	Freezing level	20.0 35.0 43.5 50.0	1875 2300 2600 2800	Open	Ram
2	---do---	20.0 35.0 43.5 50.0	1875 2300 2600 2800	---do-------	Alternate
3	---do---	20.0 35.0 43.5 50.0	1875 2300 2600 2800	Closed	Ram
4	---do---	20.0 35.0 43.5 50.0	1875 2300 2600 2800	---do-------	Alternate

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

TABLE II - INVESTIGATION OF EFFECT ON RATE OF INCREASE IN CHARGE-AIR ENTHALPY

WITH SUDDEN POWER INCREASE IN DRY AIR

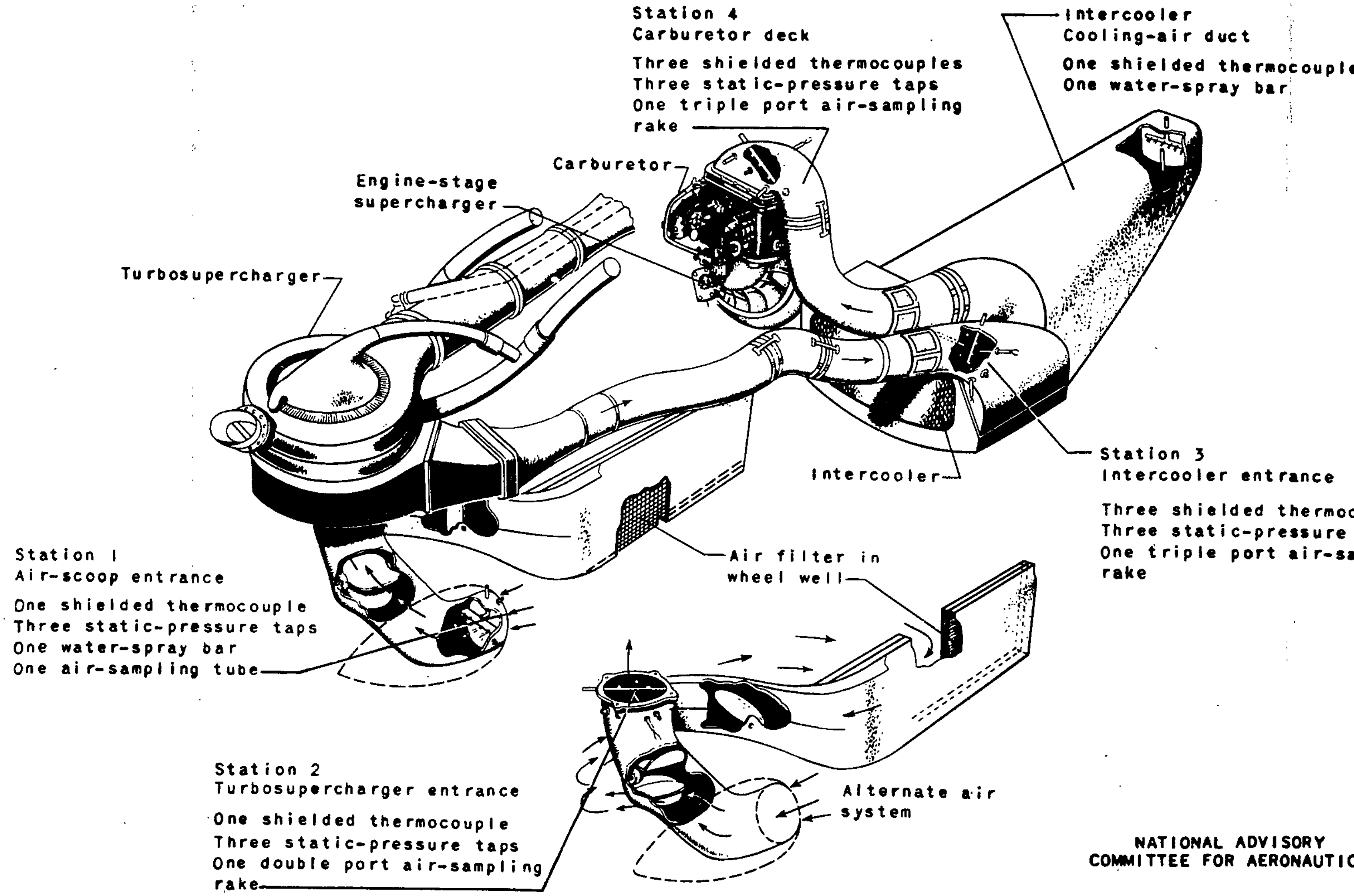
Test	Pressure altitude (ft)	Initial stabilized conditions					Increased power conditions				
		Manifold pressure (in. Hg absolute)	Engine speed (rpm)	Approximate normal rated power (percent)	Inter-cooler-flap setting	Charge-air intake	Manifold pressure (in. Hg absolute)	Engine speed (rpm)	Approximate normal rated power (percent)	Inter-cooler-flap setting	Charge-air intake
5	5,000	30.0	2200	60	Open	Ram	35.0 37.0 39.3	2300 2300 2600	75 80 90	Open	Ram
6	5,000	30.0	2200	60	Closed	---do--	35.0 37.0 39.3	2300 2300 2600	75 80 90	Closed	Do.
7	5,000	30.0	2200	60	---do--	---do--	35.0 37.0 39.3	2300 2300 2600	75 90 90	---do--	Alter-nate
8	10,000	30.0	2200	60	Open	---do--	35.0 37.0 39.3	2300 2300 2600	75 80 90	Open	Ram
9	10,000	30.0	2200	60	Closed	---do--	35.0 37.0 39.3	2300 2300 2600	75 80 90	Closed	Do.
10	10,000	30.0	2200	60	---do--	---do--	35.0 37.0 39.3	2300 2300 2600	75 80 90	---do--	Alter-nate

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

TABLE III - INVESTIGATION OF ICING CHARACTERISTICS AND NET INCREASE IN CHARGE-AIR ENTHALPY AT SIMULATED-RAIN CONDITIONS

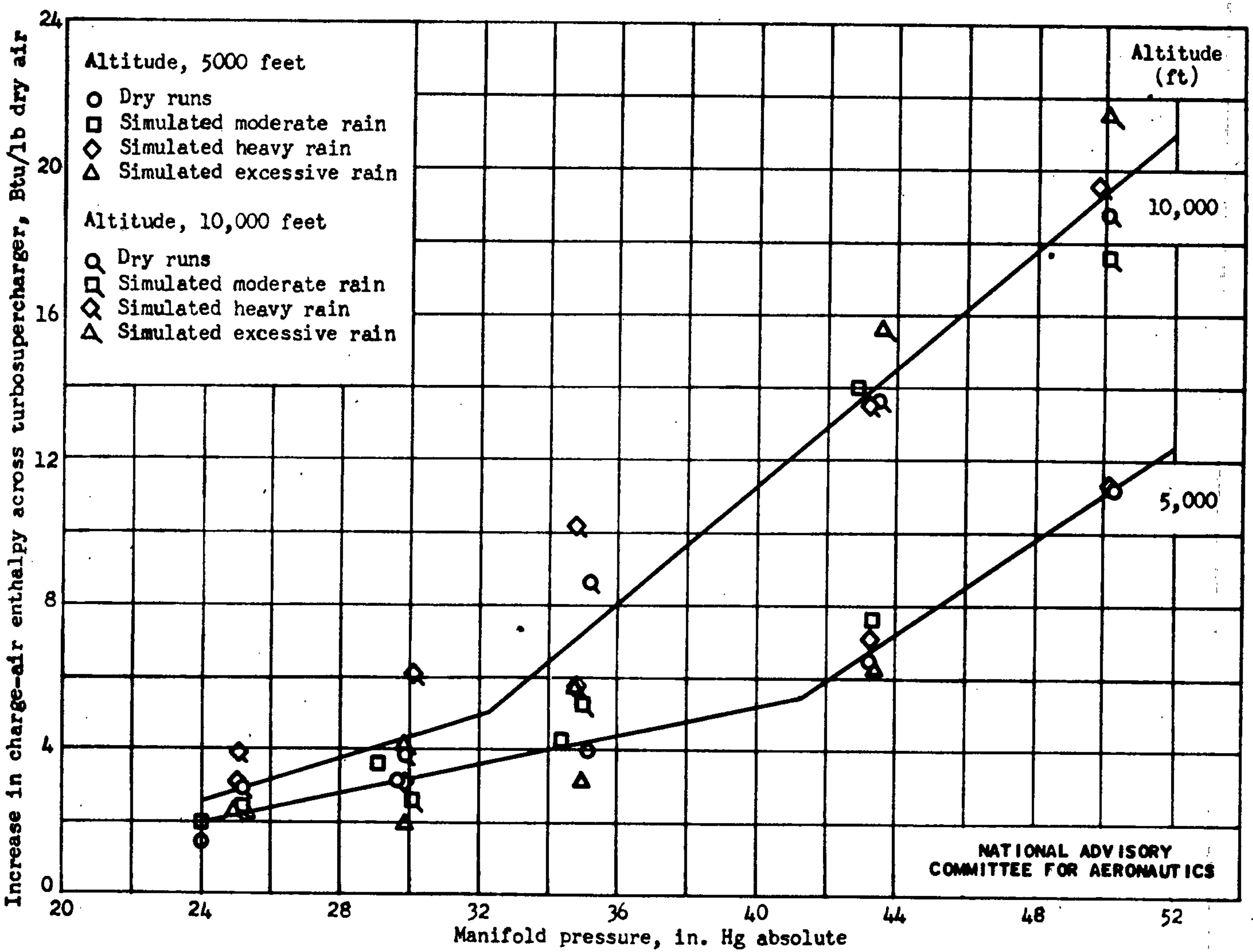
Test	Pressure altitude (ft)	Manifold pressure (in. Hg absolute)	Engine speed (rpm)	Intercooler-flap setting	Charge-air intake	Water ingestion, lb/min	
						Intercooler	Air scoop
11	5,000	25.0 30.0 35.0 43.5 50.0	2200 2200 2300 2600 2800	Open	Ram	None	None
12	5,000	25.0 30.0 35.0 43.5 50.0	2200 2200 2300 2600 2800	---do-------	---do--	0.275	0.55
13	5,000	25.0 30.0 35.0 43.5 50.0	2200 2200 2300 2600 2800	---do-------	---do--	0.55	1.10
14	5,000	25.0 30.0 35.0 43.5 50.0	2200 2200 2300 2600 2800	---do-------	---do--	1.10	2.20
15	10,000	25.0 30.0 35.0 43.5 50.0	2200 2200 2300 2600 2800	---do-------	---do--	None	None
16	10,000	25.0 30.0 35.0 43.5 50.0	2200 2200 2300 2600 2800	---do-------	---do--	0.275	0.55
17	10,000	25.0 30.0 35.0 43.5 50.0	2200 2200 2300 2600 2800	---do-------	---do--	0.55	1.10
18	10,000	25.0 30.0 35.0 43.5 50.0	2200 2200 2300 2600 2800	---do-------	---do--	1.10	2.20

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Figure 1. - Right-engine induction system of a twin-engine fighter airplane instrumented for flight icing tests.



Manifold pressure, in. Hg absolute

Figure 2. - Enthalpy increase in charge air passing through turbosupercharger; intercooler flaps open.

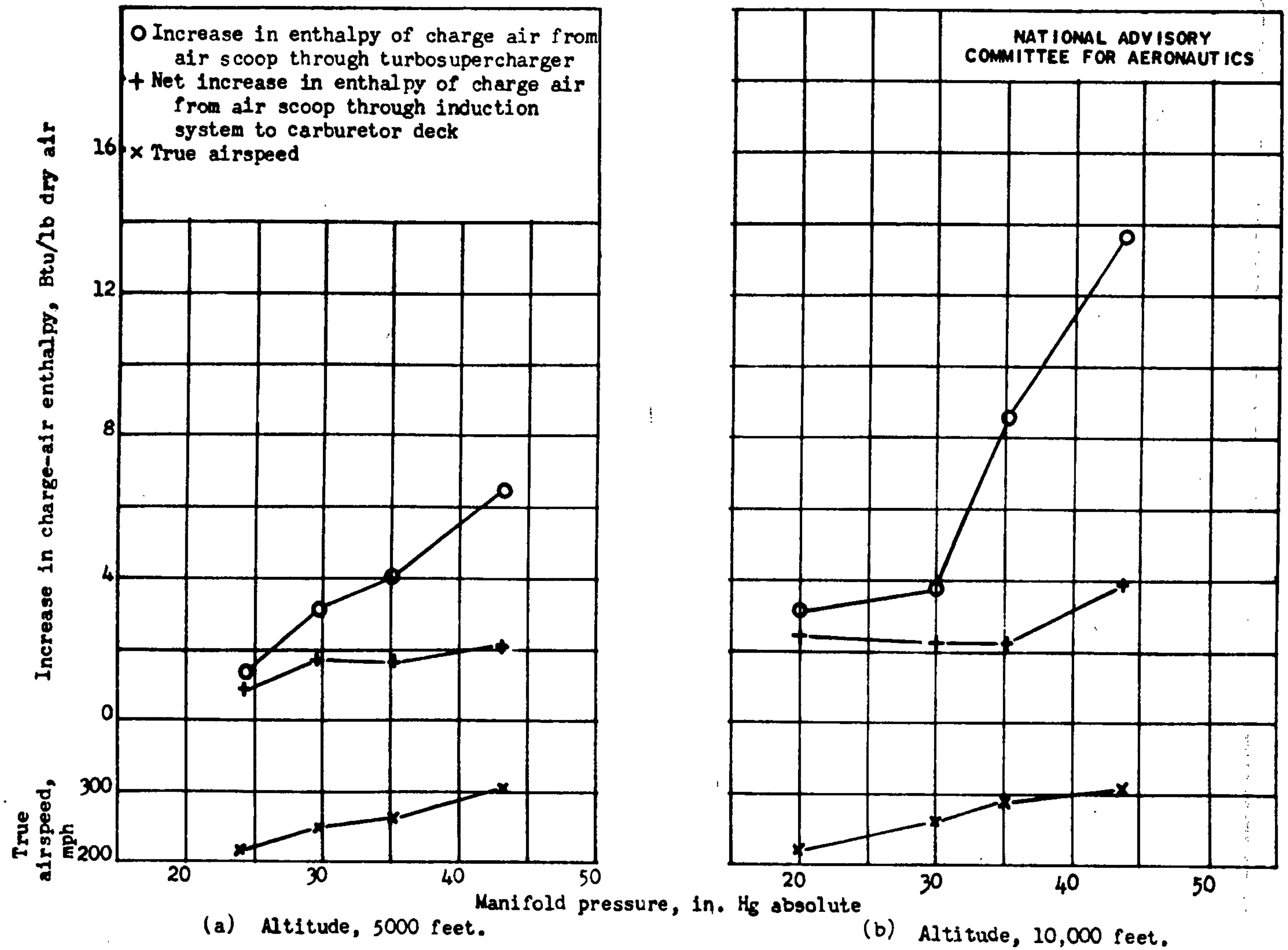
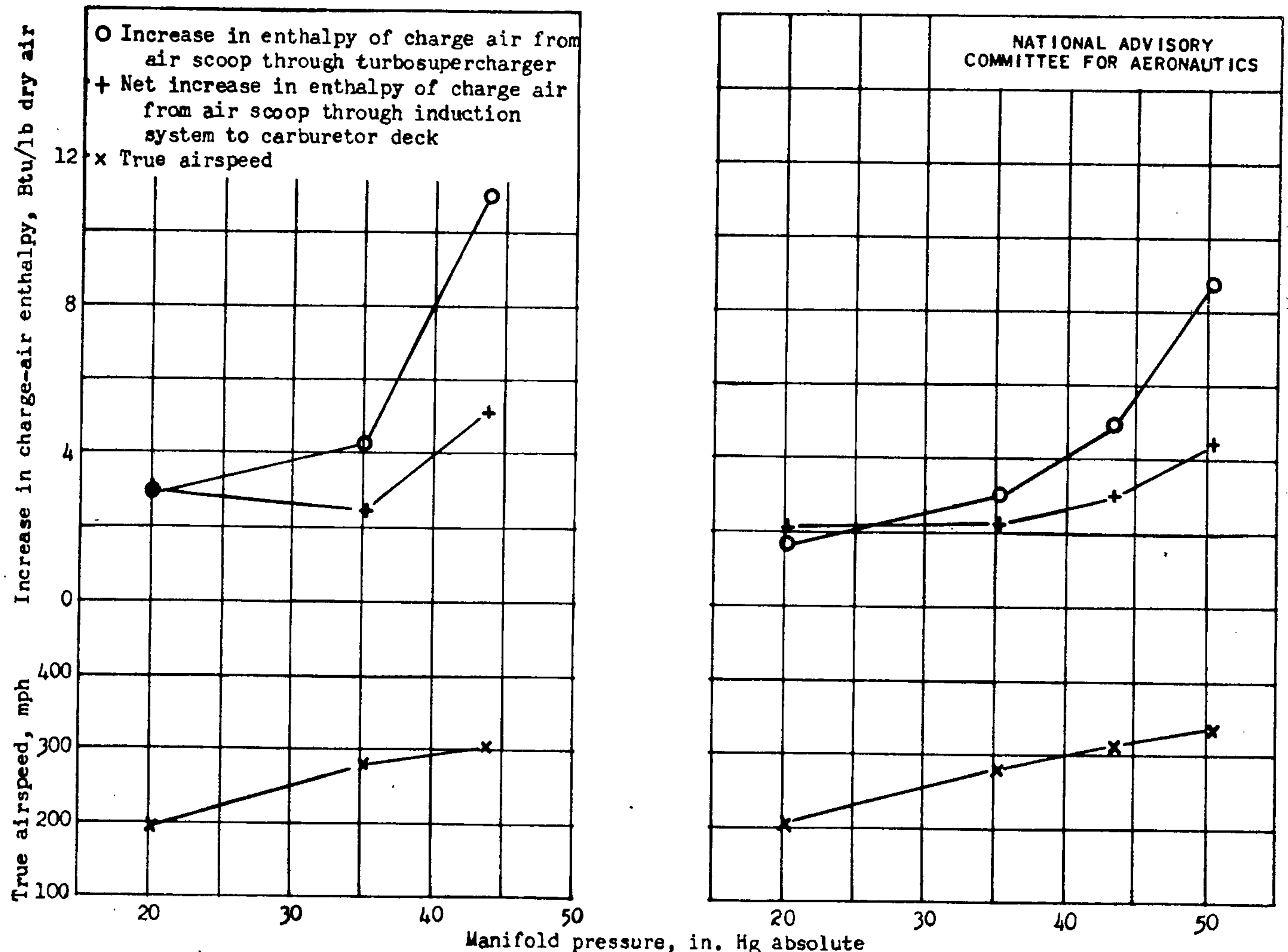


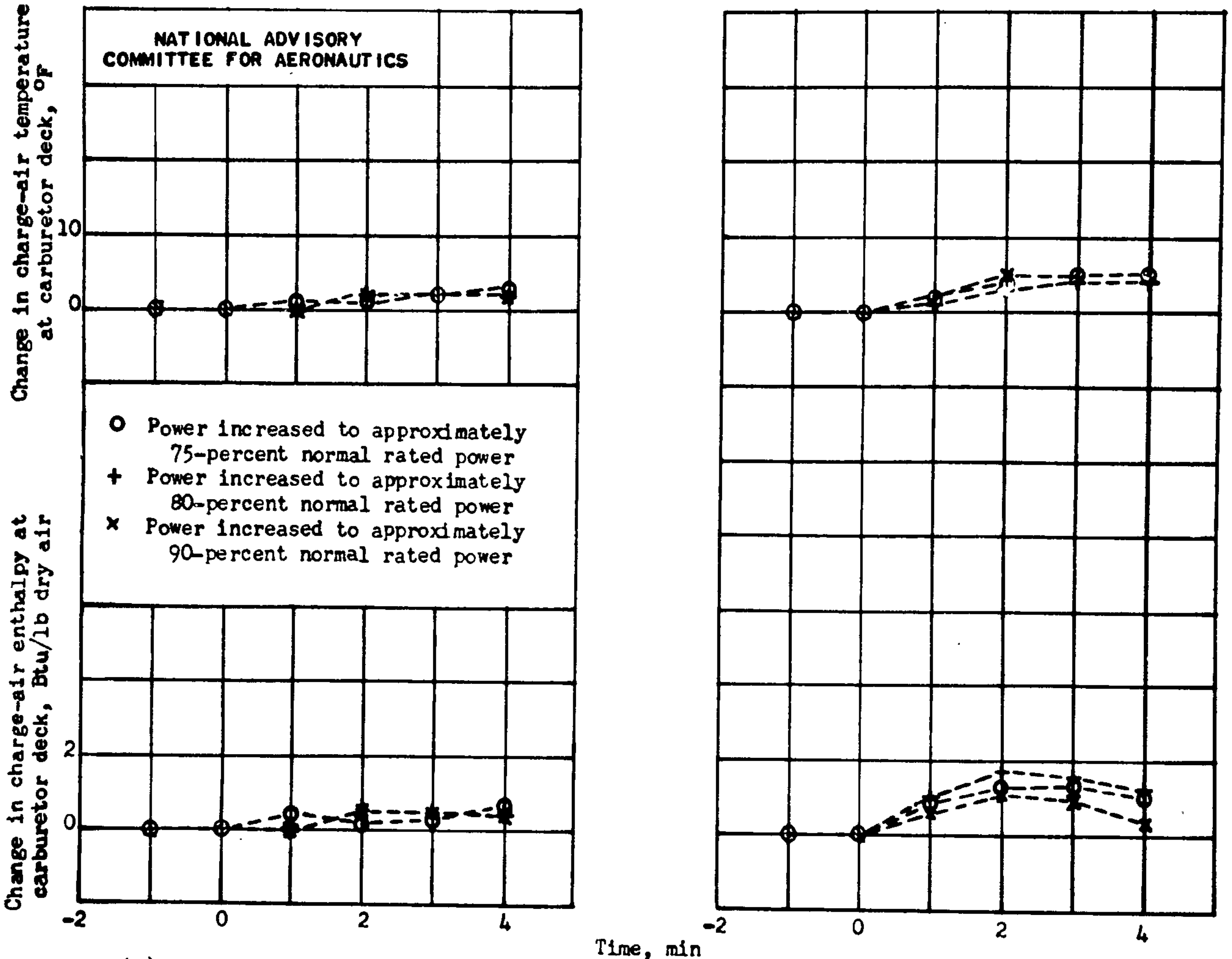
Figure 3. - Effect of intercooler on enthalpy of charge air at altitudes of 5000 and 10,000 feet with no simulated rain; intercooler flaps full open.



(a) Alternate air intake.

(b) Ram air intake.

Figure 4. - Effect of intercooler on enthalpy of charge air at approximate altitude of 3500 feet with no simulated rain; intercooler flaps full closed.



(a) Altitude, 5000 feet.

(b) Altitude, 10,000 feet.

Figure 5. - Enthalpy and temperature rise of charge air resulting from sudden increase in engine power from initial power setting of 60-percent normal rated power with ram air intake and intercooler flap in full-open position.

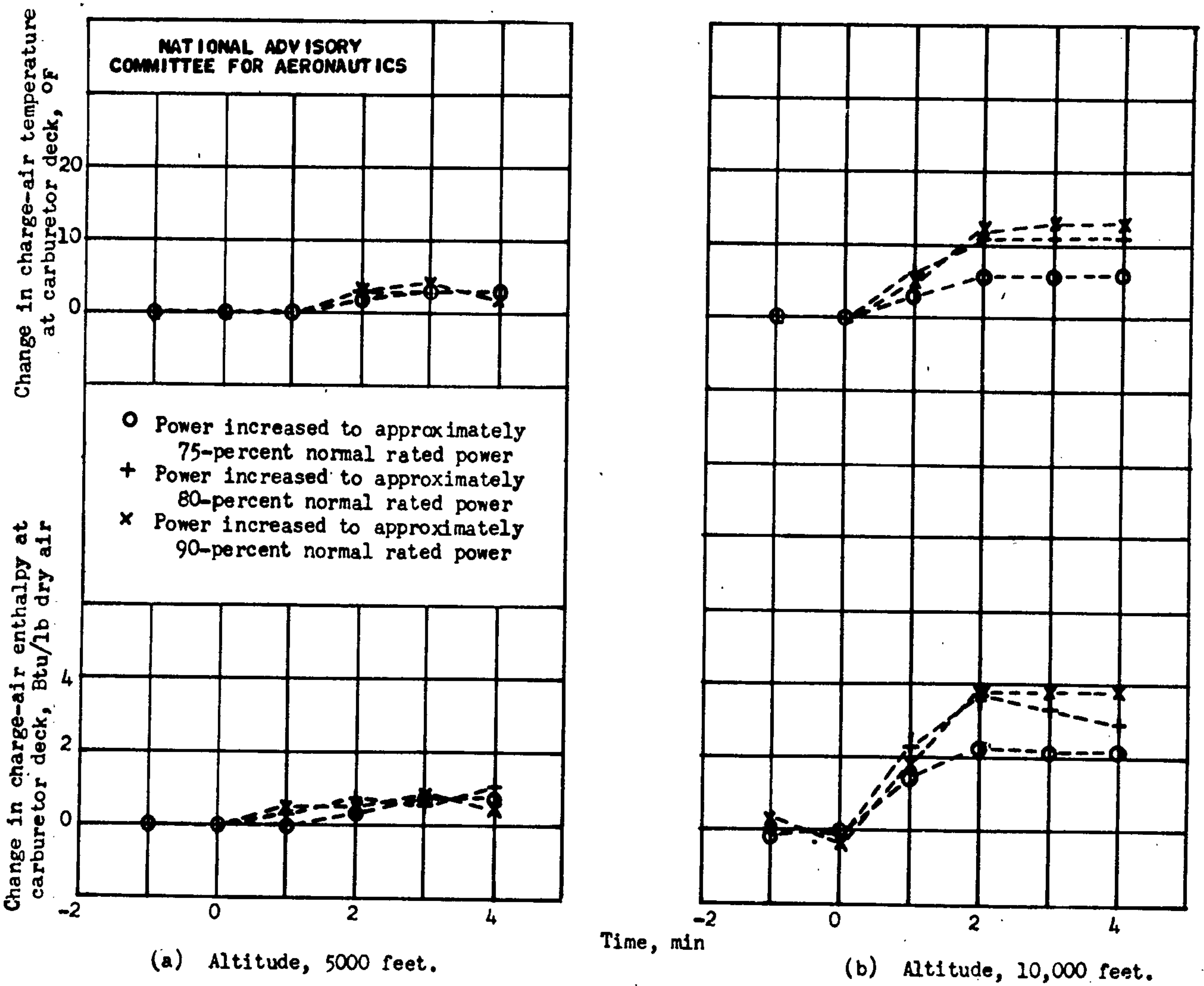


Figure 6. - Enthalpy and temperature rise of charge air resulting from sudden increase in engine power from initial power setting of 60-percent normal rated power with ram air intake and intercooler flap in full-closed position.

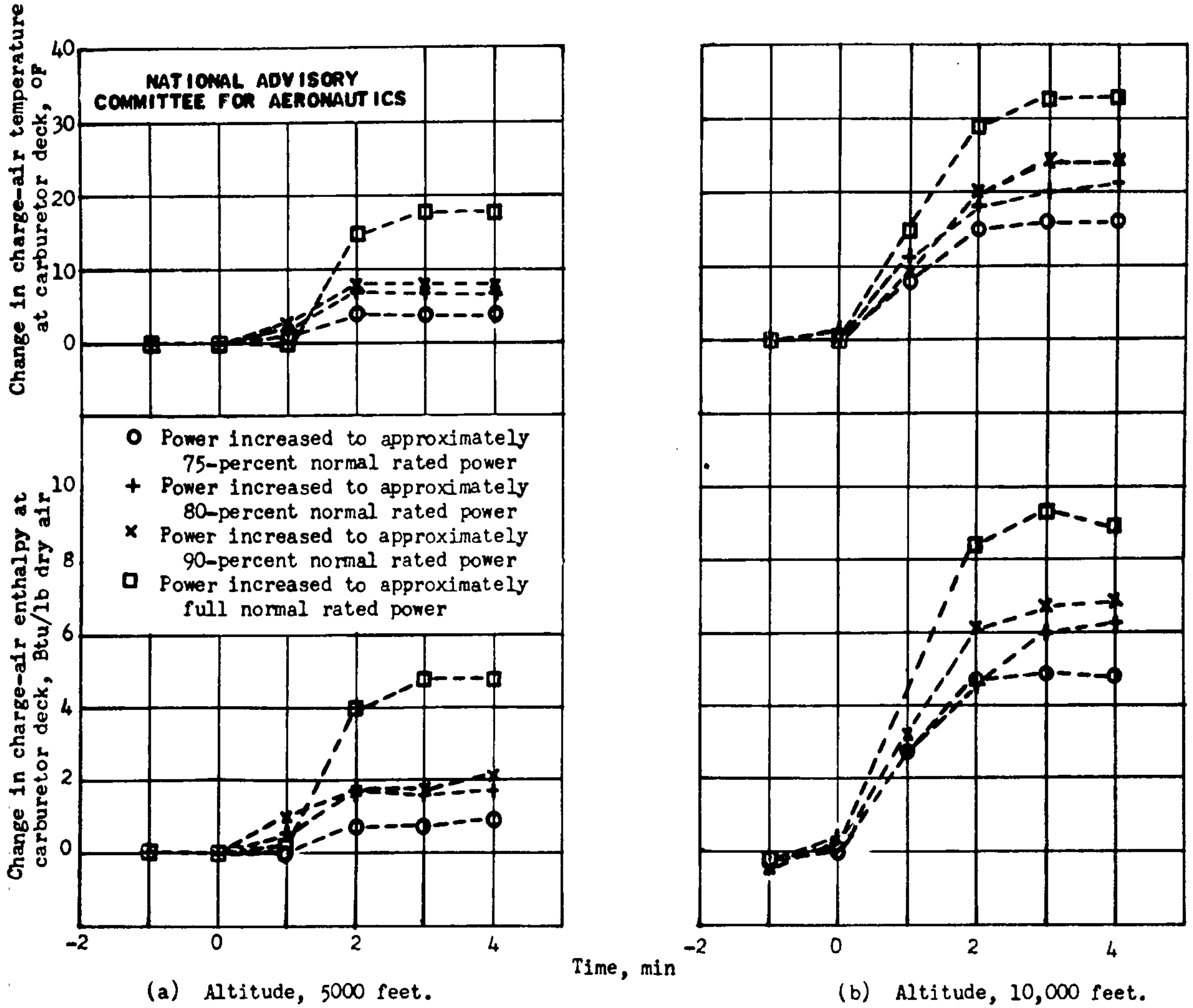


Figure 7. - Enthalpy and temperature rise of charge air resulting from sudden increase in engine power from initial power setting of 60-percent normal rated power and change from ram air intake to alternate air intake with intercooler flap in full-closed position.

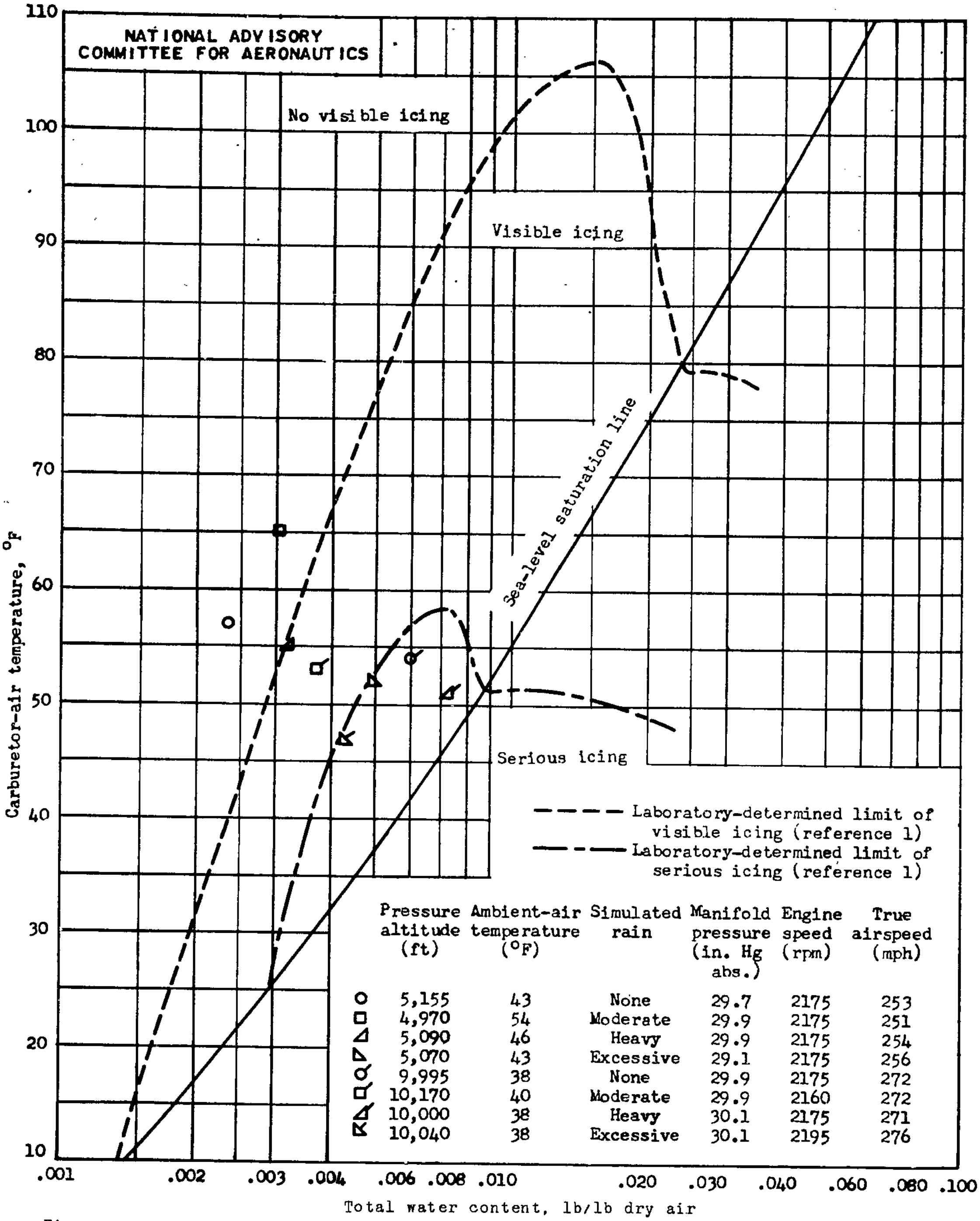
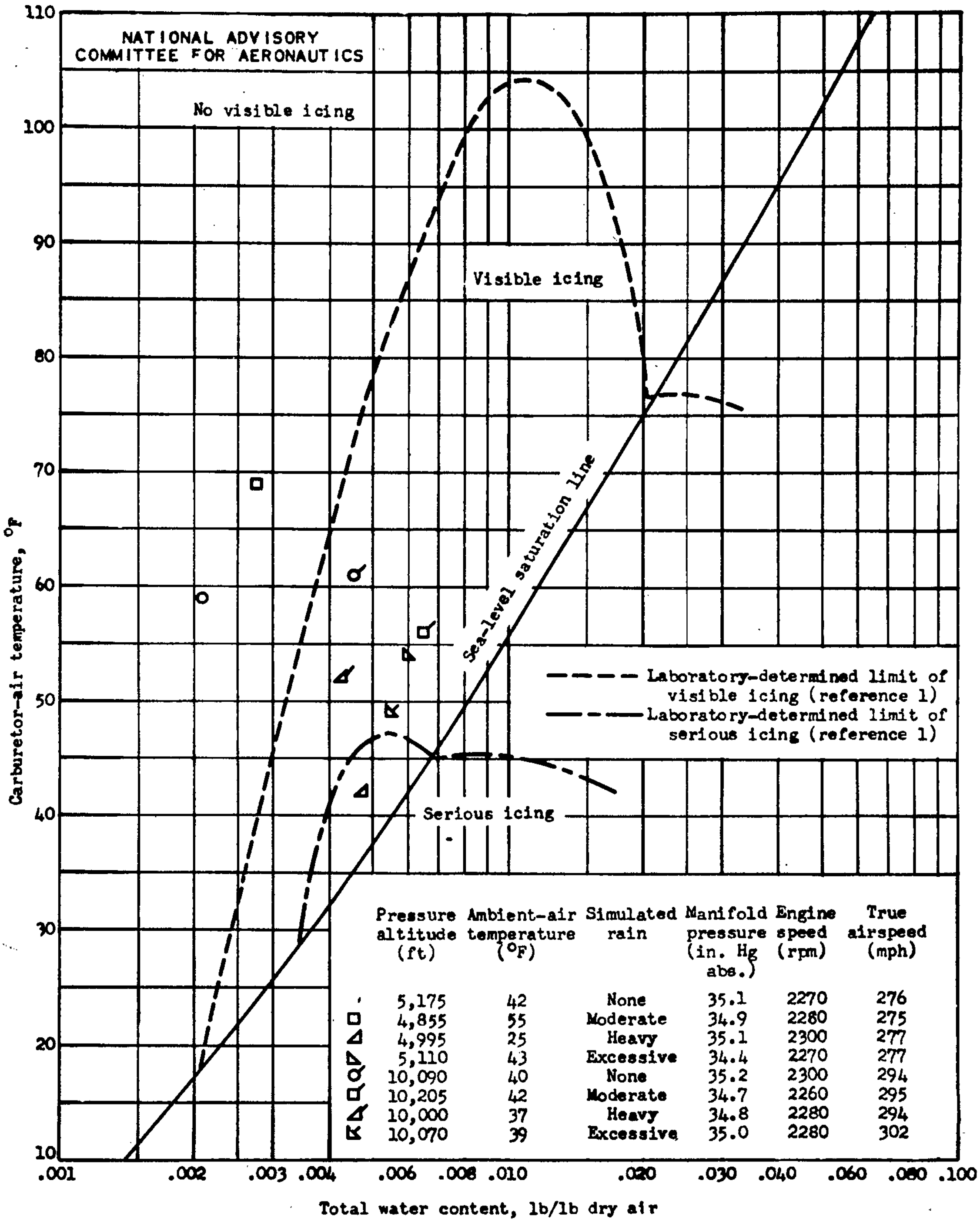
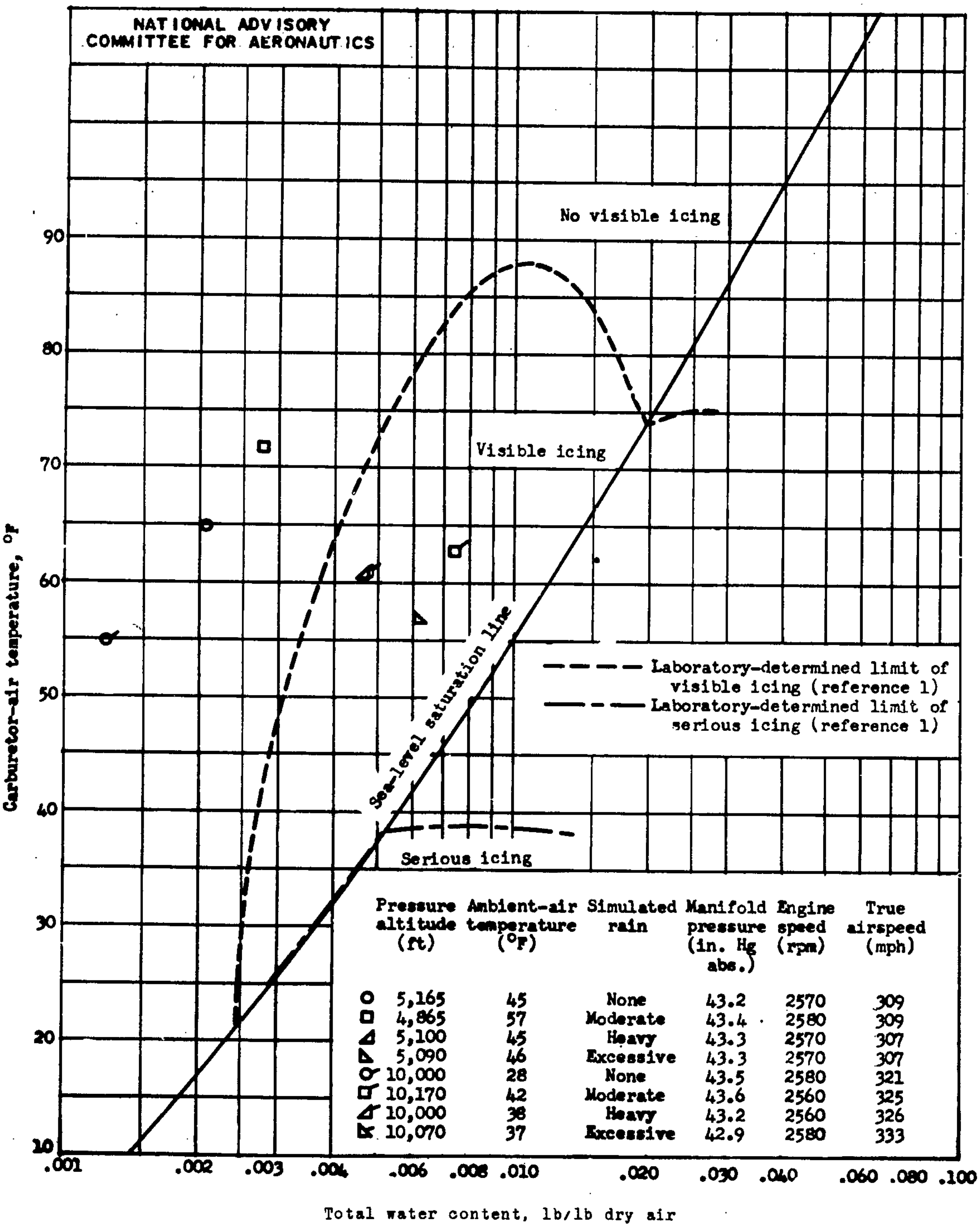


Figure 8. - Comparison of laboratory and flight icing characteristics at low cruise power. (Curves from laboratory tests of reference 1.)



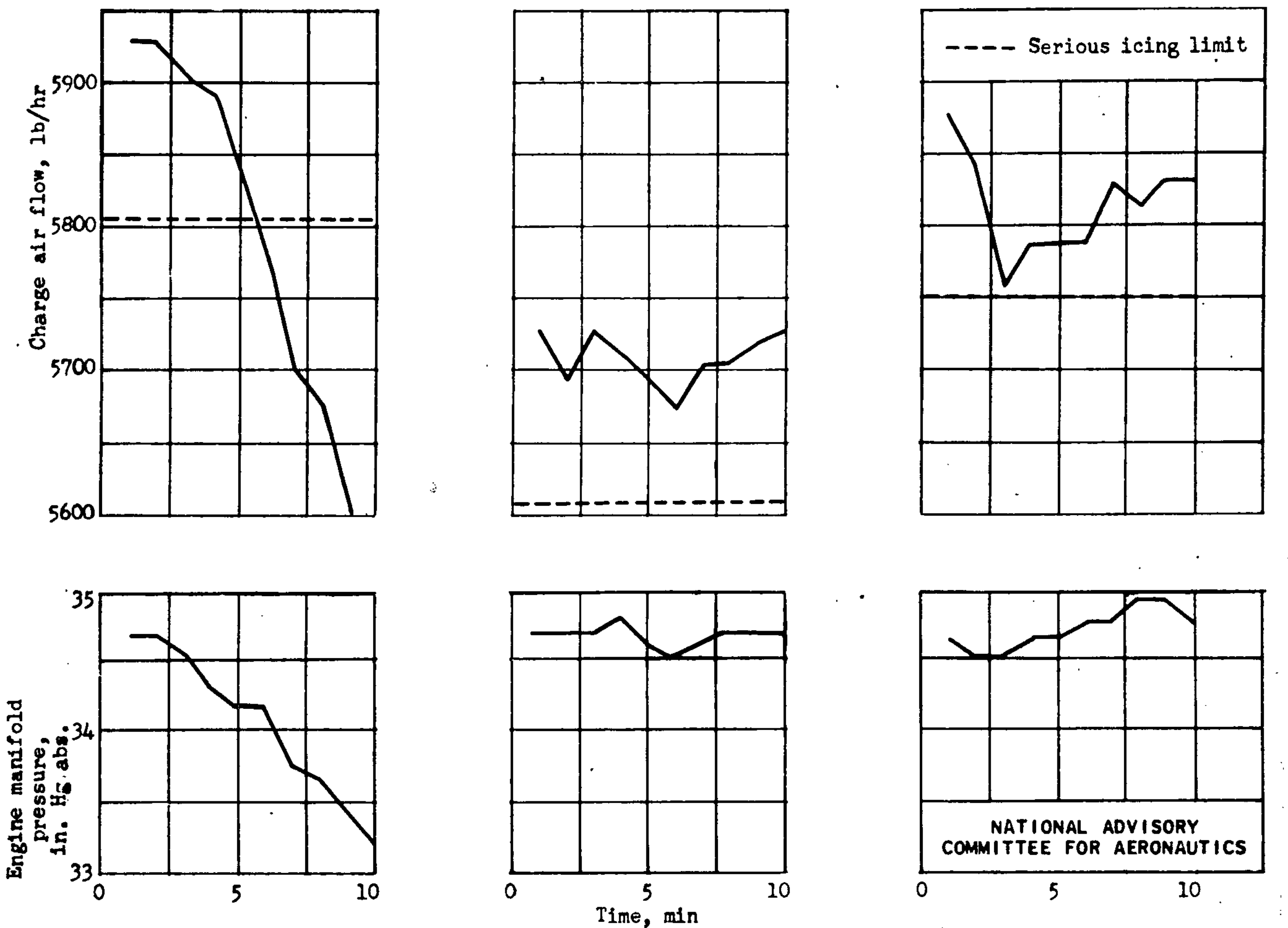
Pressure altitude (ft)	Ambient-air temperature (°F)	Simulated rain	Manifold pressure (in. Hg abs.)	Engine speed (rpm)	True airspeed (mph)
5,175	42	None	35.1	2270	276
4,855	55	Moderate	34.9	2260	275
4,995	25	Heavy	35.1	2300	277
5,110	43	Excessive	34.4	2270	277
10,090	40	None	35.2	2300	294
10,205	42	Moderate	34.7	2260	295
10,000	37	Heavy	34.8	2280	294
10,070	39	Excessive	35.0	2280	302

Figure 9. - Comparison of laboratory and flight icing characteristics at high cruise power. (Curves from laboratory tests of reference 1.)



	Pressure altitude (ft)	Ambient-air temperature (°F)	Simulated rain	Manifold pressure (in. Hg abs.)	Engine speed (rpm)	True airspeed (mph)
○	5,165	45	None	43.2	2570	309
□	4,865	57	Moderate	43.4	2580	309
◿	5,100	45	Heavy	43.3	2570	307
◺	5,090	46	Excessive	43.3	2570	307
○ (flagged)	10,000	28	None	43.5	2580	321
□ (flagged)	10,170	42	Moderate	43.6	2560	325
◿ (flagged)	10,000	38	Heavy	43.2	2560	326
◺ (flagged)	10,070	37	Excessive	42.9	2580	333

Figure 10. - Comparison of laboratory and flight icing characteristics at normal rated power. (Curves from laboratory tests of reference 1.)



(a) Ram air intake; ambient-air temperature, 20° F; altitude, 9737 feet; true airspeed, 292 mph; engine speed, 2270 rpm.

(b) Alternate air intake; ambient-air temperature, 19° F; altitude, 9638 feet; true airspeed, 290 mph; engine speed, 2280 rpm.

(c) Ram air intake; ambient-air temperature, 28° F; altitude, 10,105 feet; true airspeed, 294 mph; engine speed, 2280 rpm.

Figure 11. - Effect of air-scoop impact icing on air flow and engine manifold pressure.